Offshore Wind Energy Fundamentals for Bangladesh

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National Renewable Energy Laboratory (NREL)

Training in collaboration with the Sustainable and Renewable Energy Development Authority of Bangladesh (SREDA)
June 2024

Image: Gary Norton (DOE)

NREL at a Glance

3,675 workforce, including:

- 2,732 regular/limited term
- 490 contingent workers
- 211 postdoctoral researchers
- 152 graduate student interns
- 90 undergraduate student interns

—as of 9/30/2023

World-class research expertise in:

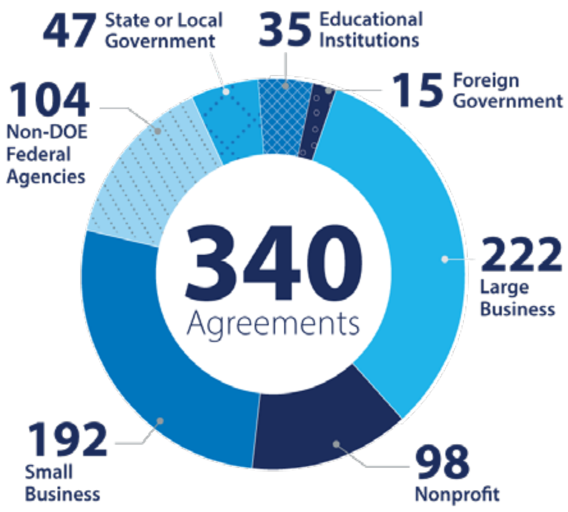
- Renewable Energy
- Sustainable Transportation & Fuels
- Buildings and Industry
- Energy Systems Integration

Partnerships with:

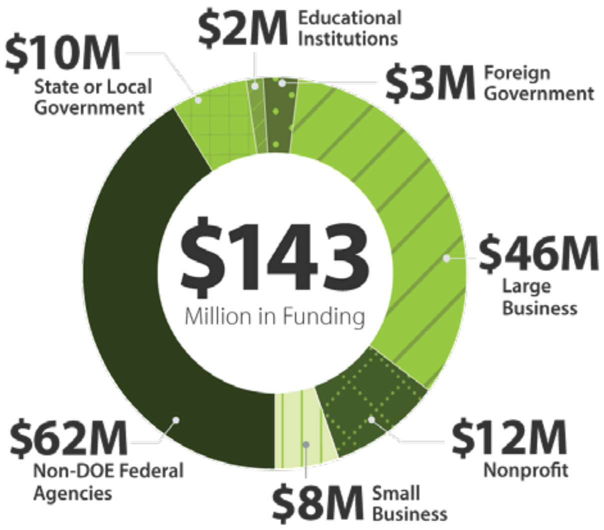
- Industry
- Academia
- Government

4 campuses operate as living laboratories

More Than 1,000 Active Partnerships in FY 2023



Agreements by Business Type



Funding by Business Type

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Context for Offshore Wind in Bangladesh

Why Pursue Offshore Wind Energy?

- ✓ Generation close to load (much of the world's population lives near the coast)
- ✓ Stronger wind resource with higher capacity factor and potentially different generation profile
- ✓ Larger scale clean energy projects are possible
- ✓ Less constrained by land transport and construction
- ✓ Revitalizes ports and domestic manufacturing

For Bangladesh:

Diversify the country's renewable energy mix without using limited land.

Leverage investments in coastal economic zones to support offshore wind manufacturing and installation.

Transfer skillsets from offshore oil and gas exploration to offshore wind development.

Global Development Trends

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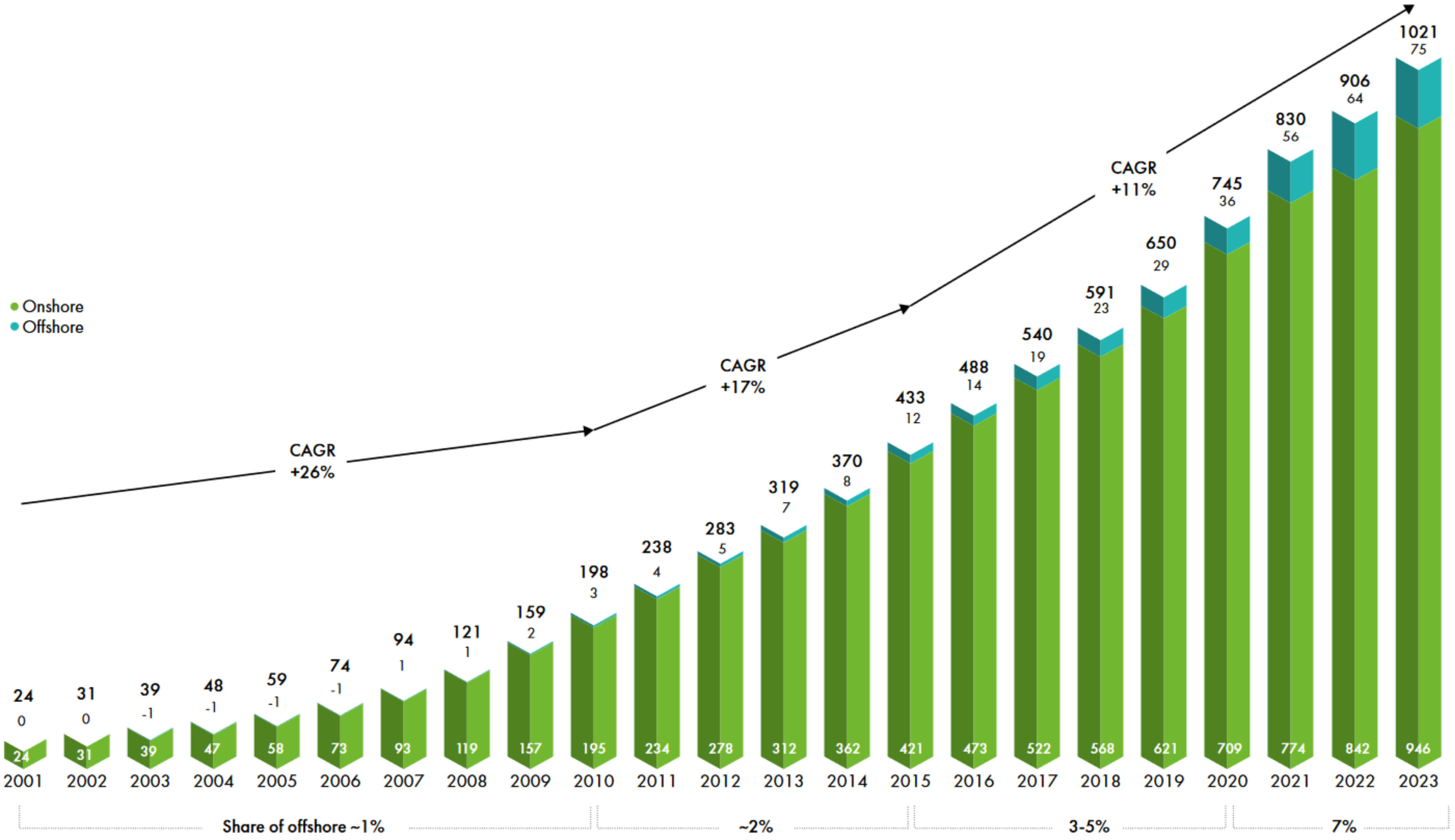

Figure. Global installed capacity of wind (GW), 2001-2023

Source: Lee and Zhao (2024)

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Market Share by Region

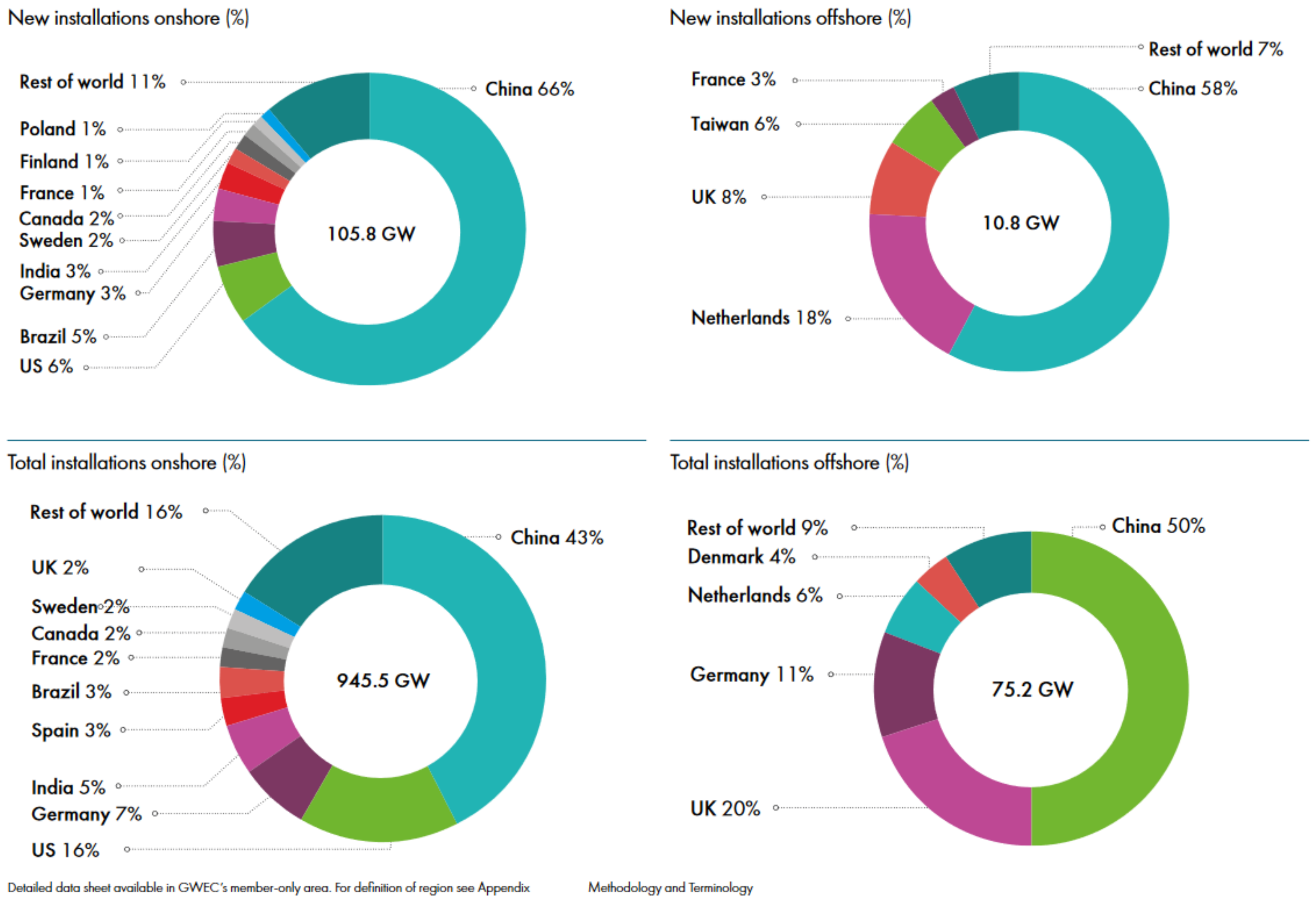

Figure. Percentage of new and total onshore and offshore wind installations by country (2023)

Source: Lee and Zhao (2024)

Cost Trends and Projections

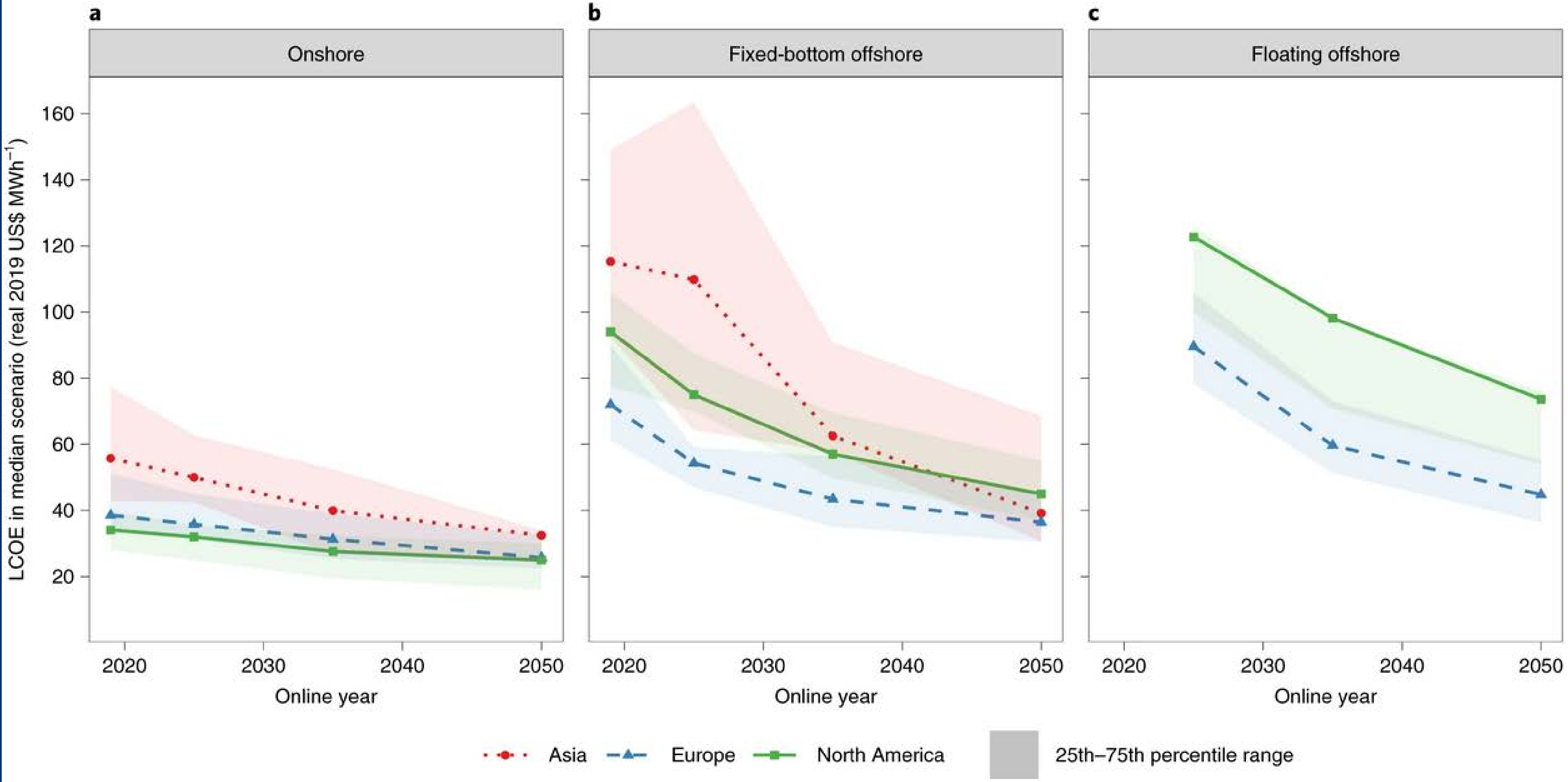

Figure. Median-scenario wind LCOE projections from 2020 survey of experts, 2021-2050

Note: *like other industries, the wind industry has been impacted by supply chain shocks, inflation, and rising interest rates over the past several years, resulting in higher costs today than what was reported in 2020. There is still long-term potential for cost reductions enabled through increased deployment, industry learning and innovation, and supply chain maturation.*

Source: Wiser et al. (2021)

Technology Trends

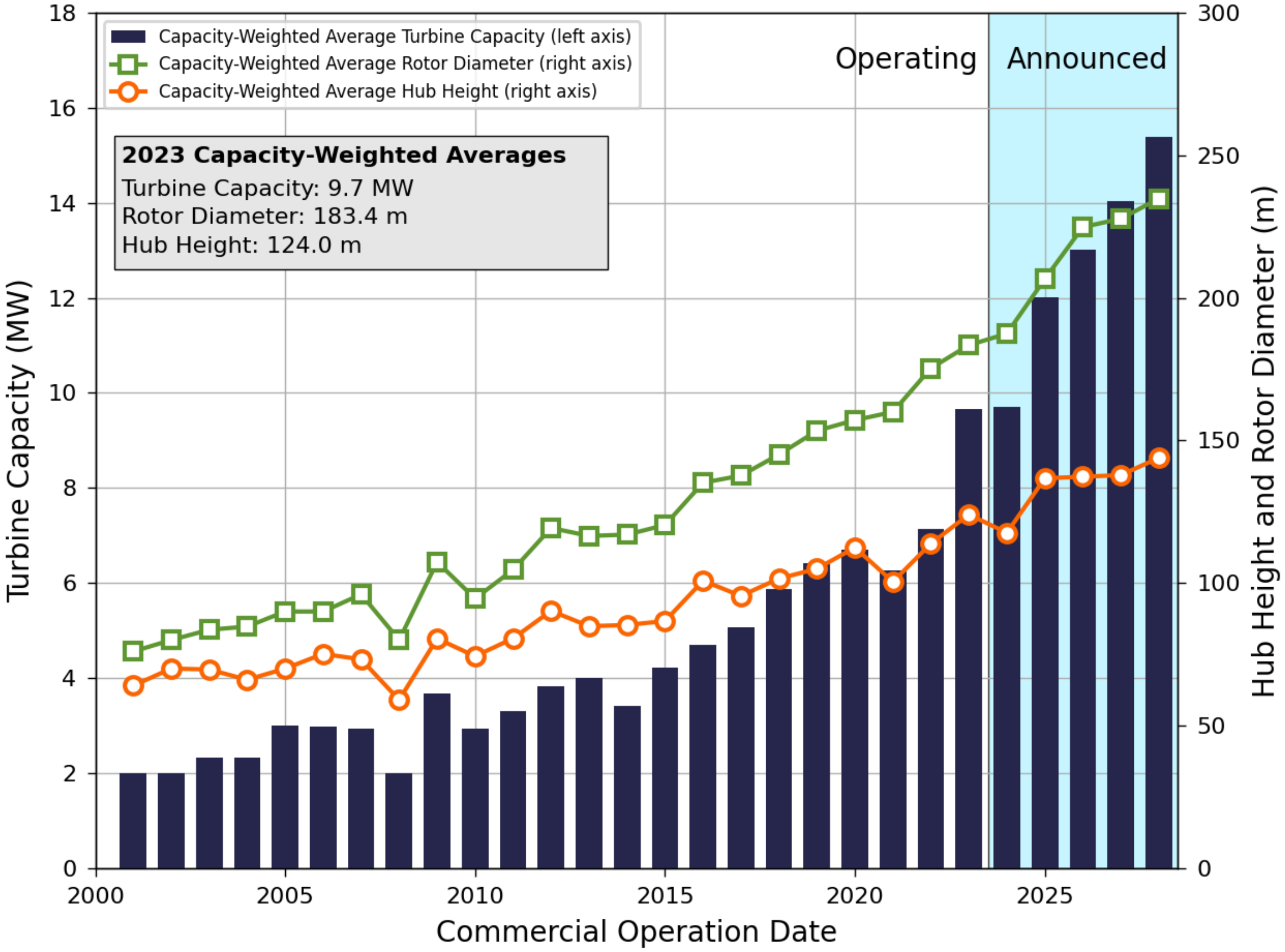

Figure. Trends in offshore wind turbine technology

Figure. Wind turbine blade manufacturing and testing facility tour for Bangladesh government officials during visit to NREL

Image: Werner Slocum (NREL)

Source: NREL Offshore Wind Market Report: 2024 Edition (forthcoming)

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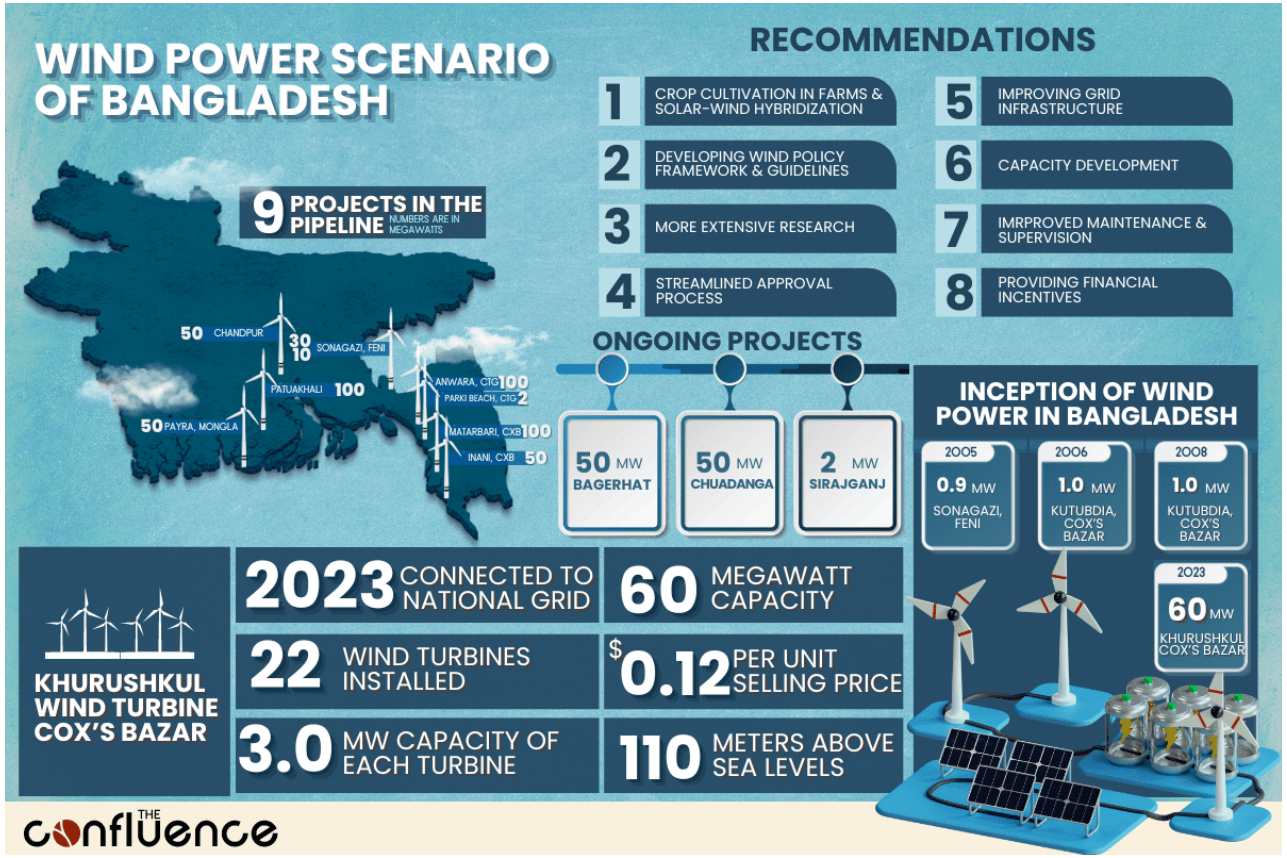
Wind Energy Sector in Bangladesh

- Bangladesh aims to have 5 GW of total installed wind capacity (onshore and offshore) by 2032.

- Current installed capacity of wind: 63 MW (with one commercial-scale plant at 60 MW).

Figure. Current landscape of wind energy in Bangladesh



Source: Uzzaman (2023)

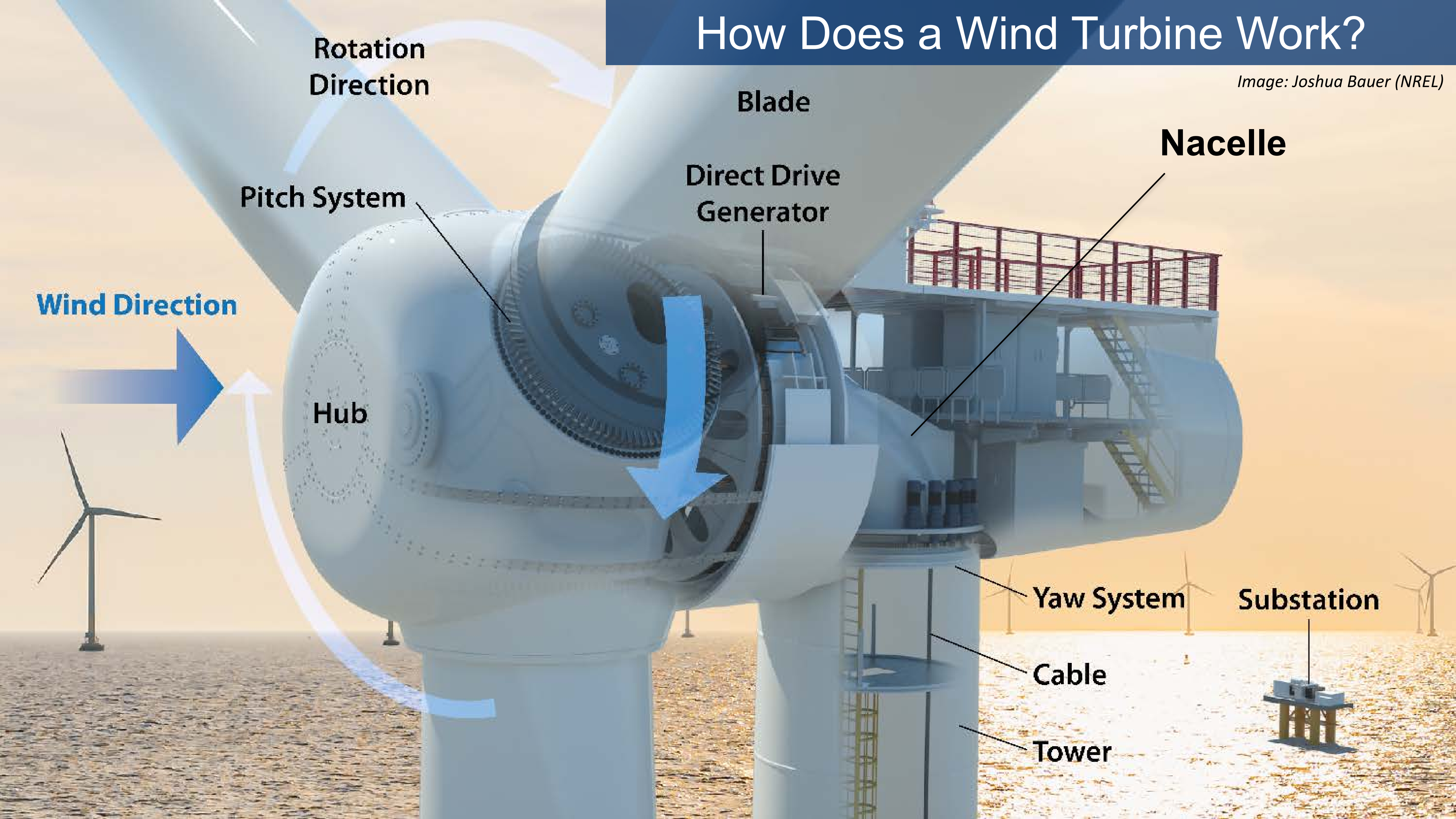
Offshore Wind Development in Bangladesh

- The Asian Development Bank (ADB) has sponsored pre-feasibility and feasibility assessments for offshore wind in the Bay of Bengal and identified suitable areas for further study and initial development off the coast of Cox's Bazar.
- H&M is investing in an offshore wind project, led by Copenhagen Infrastructure Partners. This project anticipates:
  - Detailed feasibility study for this site will be conducted within the next 3 years.
  - 500 MW plant which could begin operation by 2028.
- Bangladesh Integrated Energy and Power Master Plan (IEPMP) 2023 plans for 6 GW of offshore wind by 2041 and 15 GW by 2050 in the Advanced Technology Scenario.

Sources: Sajid (2023), Clancy (2024), Bangladesh Ministry of Power, Energy and Mineral Resources (2023)

Offshore Wind Technology Basics

How Does a Wind Turbine Work?



Power from Wind

$$P_{wind} = E\frac{1}{2}\rho A v^3$$

P_{wind} = power extracted from wind

E = efficiency of the turbine

ρ = density of the air

A = swept area of the turbine = πr^2

r = radius of the rotor

v = wind speed

Greater power extraction:

Select high wind speed sites (v^3)

Increase in turbine height allows access to lower density air (ρ) and higher wind speeds (v^3)

Increase in rotor radius (r^2) results in larger swept area (A)

Source: Joshi and Gokhale-Welch (2022)

Wind Resource Characteristics

Mean Wind Speed: “Average annual (or longer term) wind speed.”

Wind Speed Distribution: “How many hours per year does the wind blow at (x) m/s?”

Wind Direction: *“*How often and how strong are the winds from particular directions?”

Diurnal Wind Distribution: “What time of day has the most wind energy?”

Seasonal Wind Distribution: “What time of year has the strongest wind resource?”

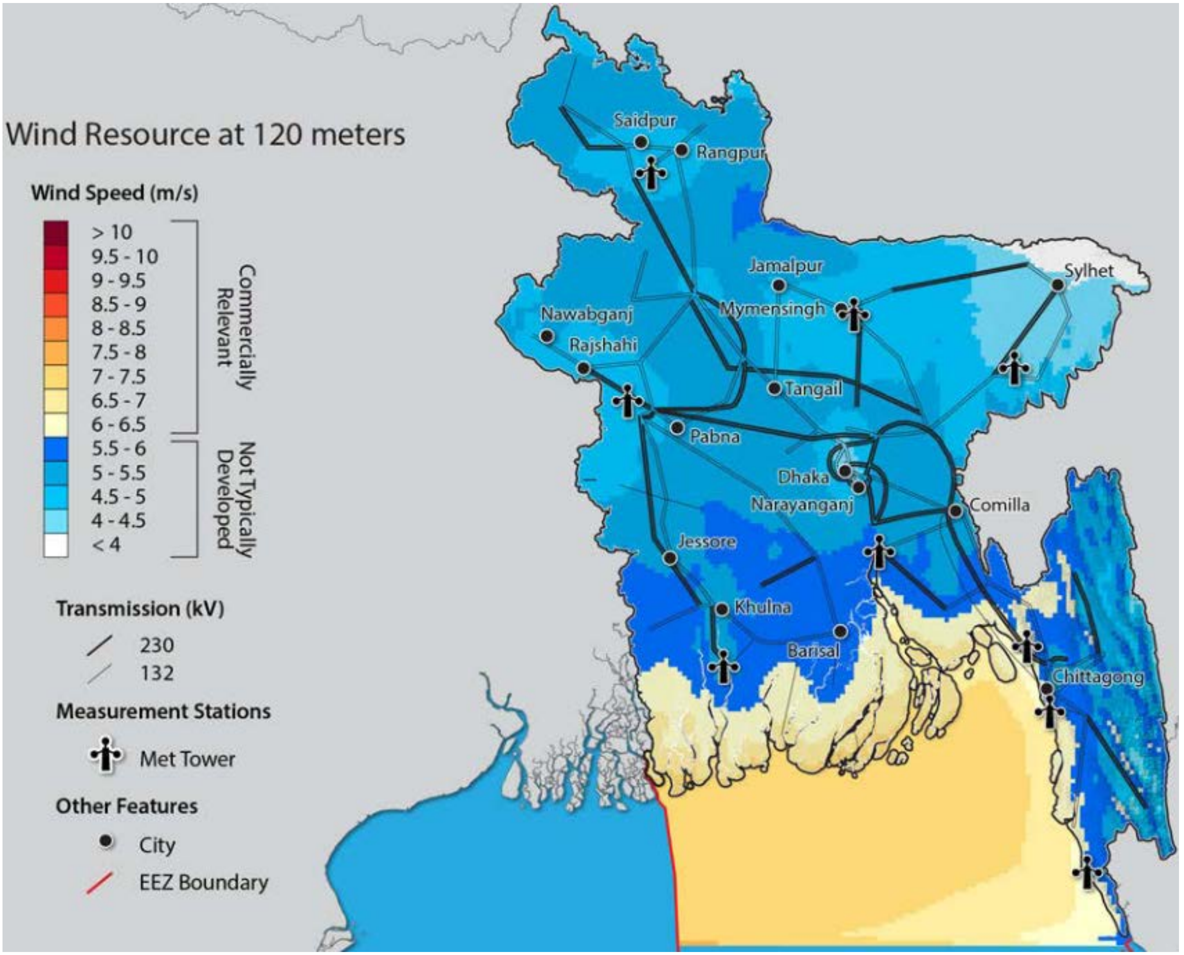


Figure. Modeled and measured wind speeds at 120m in Bangladesh

Image: Jacobson et al. (2018)

Source: Robichaud (2018)

Turbine Power Curves

Cut-In Speed: Speed below which power is not generated.

Rated Wind Speed: Speed at which power is 100% of rated power.

Cut-Out Speed: Speed at which turbine shuts down to protect rotor and drive train from damage.

This is an example power curve from a wind turbine in 2014. Not all turbines will have these exact power curve characteristics.

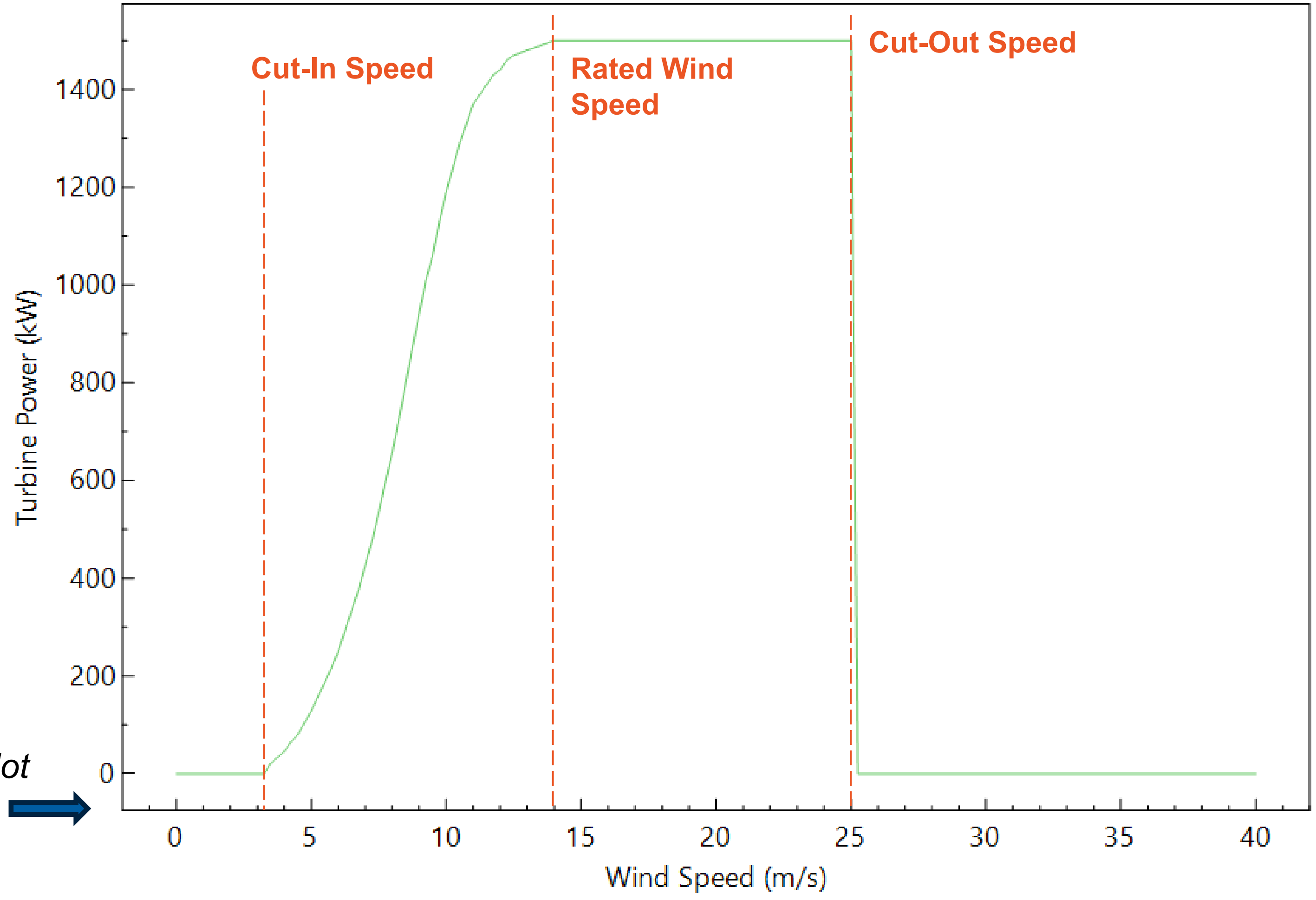


Figure. Example power curve for a wind turbine

Source: Freeman et al. (2014)

Onshore vs. Offshore Wind

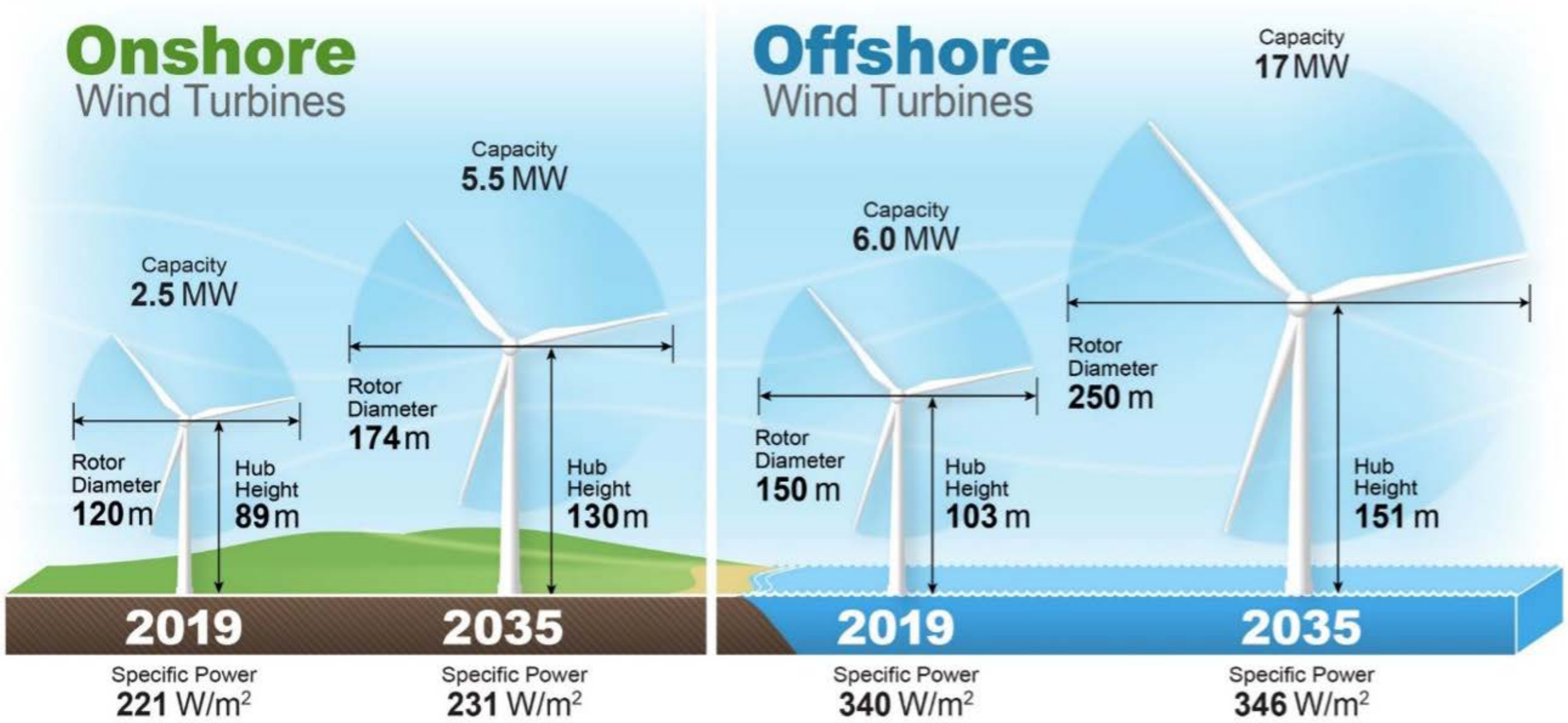


Figure. Current and projected characteristics for onshore and offshore wind turbines

Image: Lawrence Berkeley National Lab

Figure. Offshore wind project in the United States

Image: Dennis Schroeder (NREL)

- Offshore wind turbines have higher hub heights and larger rotor diameters.
- Wind speeds are typically higher, more consistent, and less turbulent offshore.
- Offshore wind farms are not constrained by land availability but have separate permitting considerations.
- Barriers to offshore wind include a lack of supporting infrastructure (vessels, cranes, ports), difficult construction conditions, and higher costs.

Source: Beiter et al. (2022)

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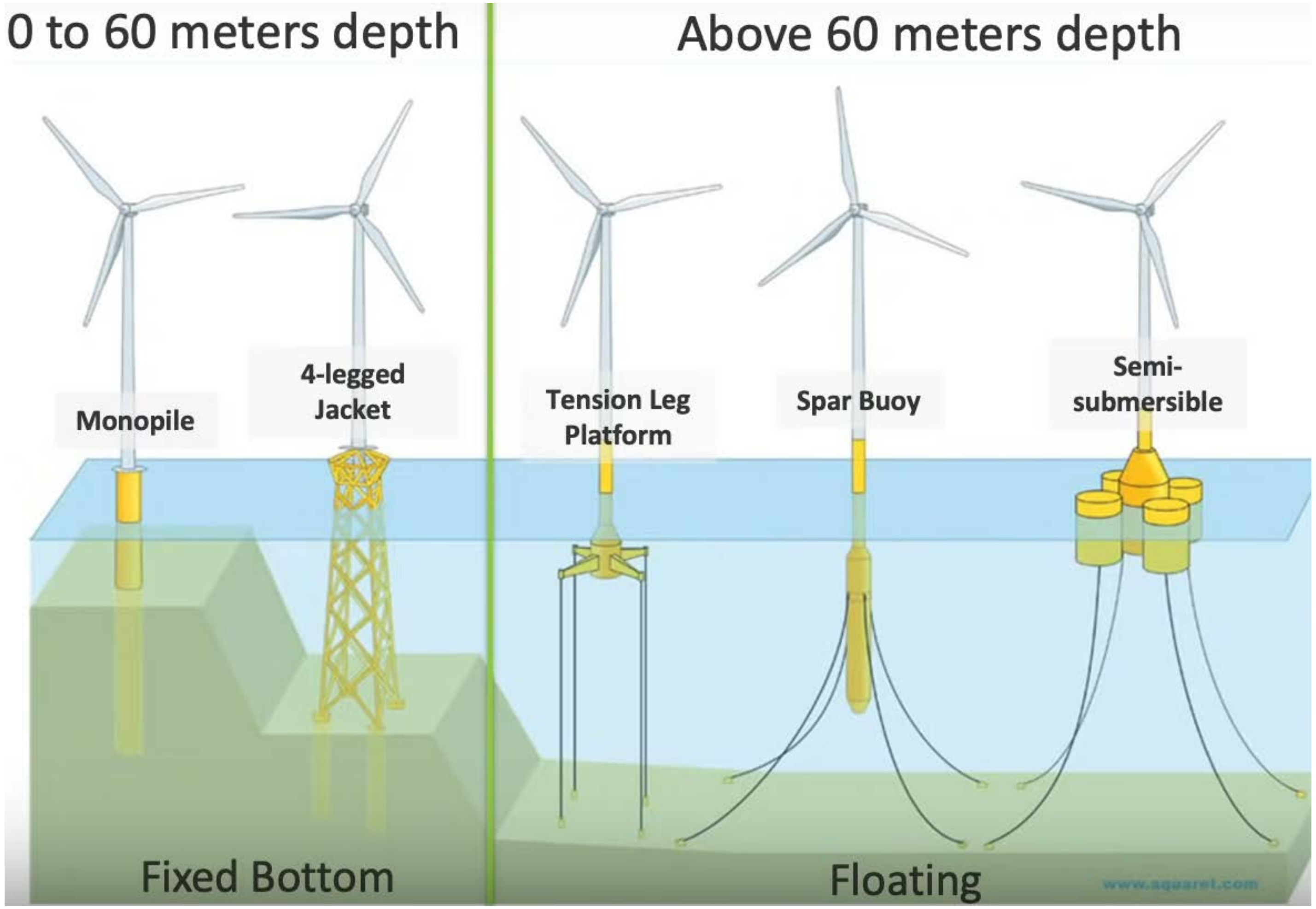
Floating vs. Fixed Technology

Figure. Structures for fixed bottom and floating offshore wind



- In water depths greater than 60 m, floating substructures may be more economical.
- "~80% of offshore wind resources are in waters greater than 60 m deep."
- Floating wind enables sites to be located further from shore, with better wind resources.

Source: Musial (2020)

Installation Technology

Figure. A jack-up barge off the shore in Virginia, United States

Images: Dominion Energy, Siemens

Figure. A jack-up barge at the Borkum Riffgat Offshore Wind Farm in the North Sea, Germany

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Considerations for Tropical Storms

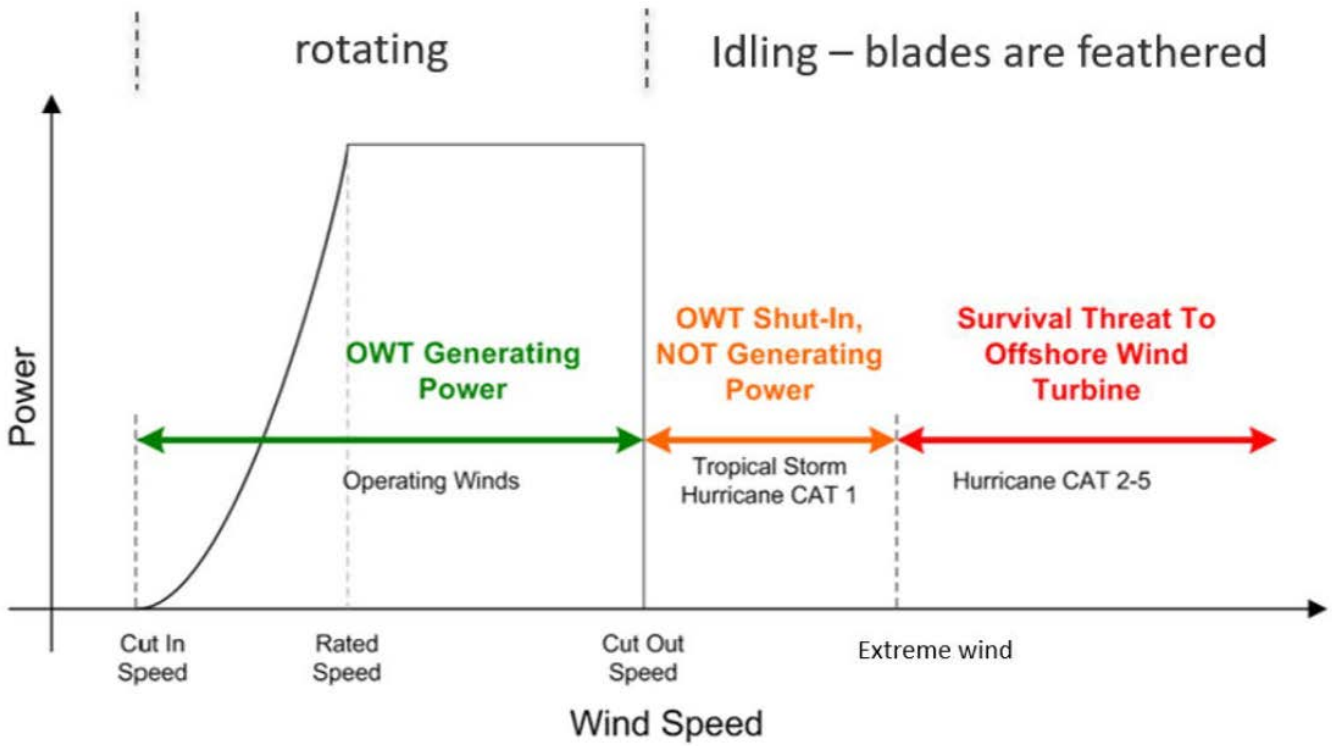

Figure. Example wind turbine power curve, extended to tropical storm conditions

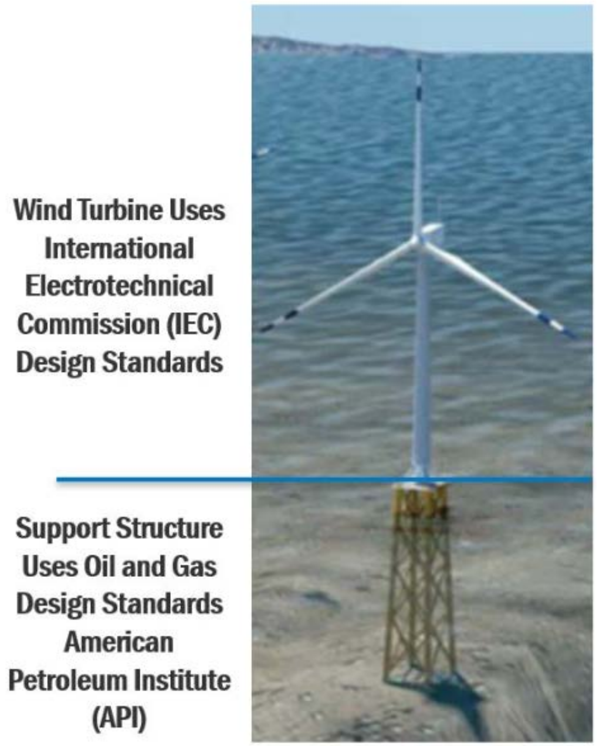

Figure. Design standards for offshore wind turbine and substructure

- When the turbine is not producing power, there are lower loads on the system (turbine will shut off due to high winds).
- Standard procedure is to orient the turbine nacelle to always face the wind because cross winds can cause higher loads.
- Grid connection is needed to power yaw system (if grid power is lost, there are additional IEC design standards to follow).

- IEC design load case (DLC) relevant to tropical cyclones: DLC 6.1 (normal condition, grid connection) and DLC 6.2 (abnormal condition, no grid connection).

Source: Fuchs et al. (2023)

Turbine Spacing Increases With Rotor Diameter

Rough estimate of power density: 4 MW/km^2

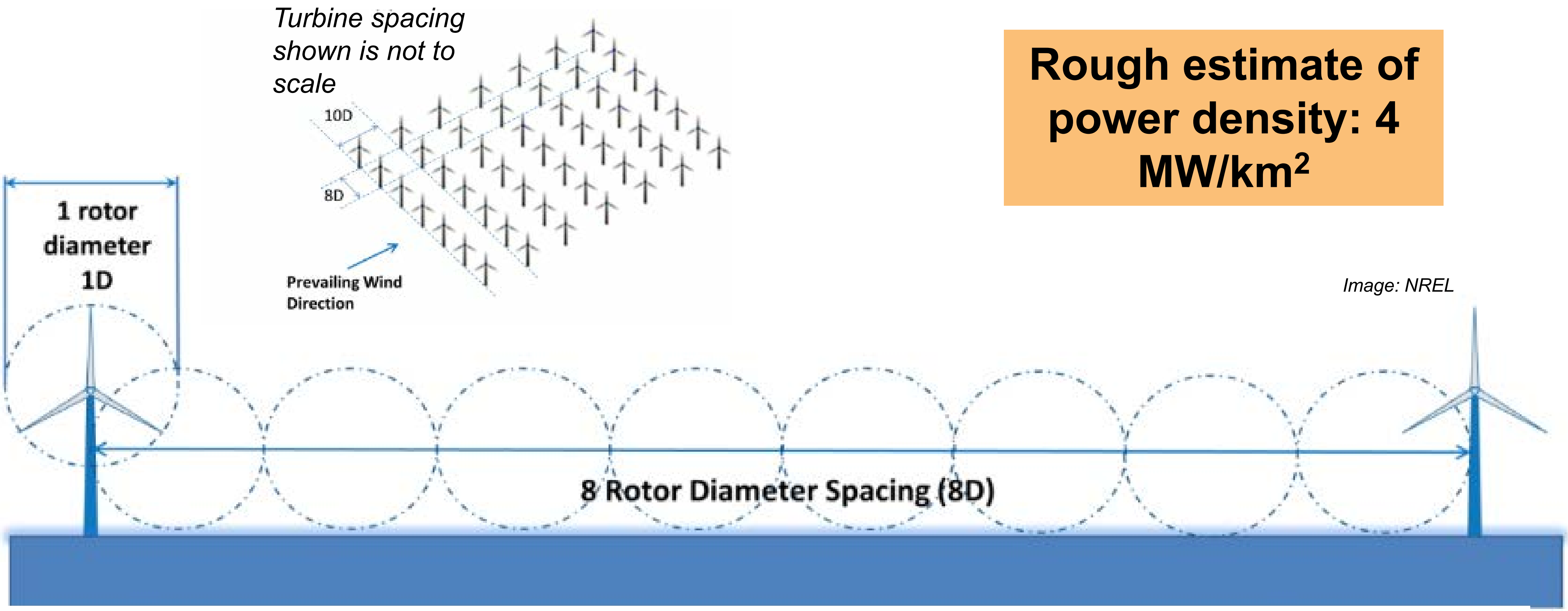

Image: NREL

Bigger spacing = higher capital cost due to longer array cables, larger array footprint, but lower wake losses – typical spacing varies between 6D and 8D

Example: For a GE 12-MW Haliade-X with 8D spacing, the turbines would be over 1.6 km apart

Offshore Wind Project Development

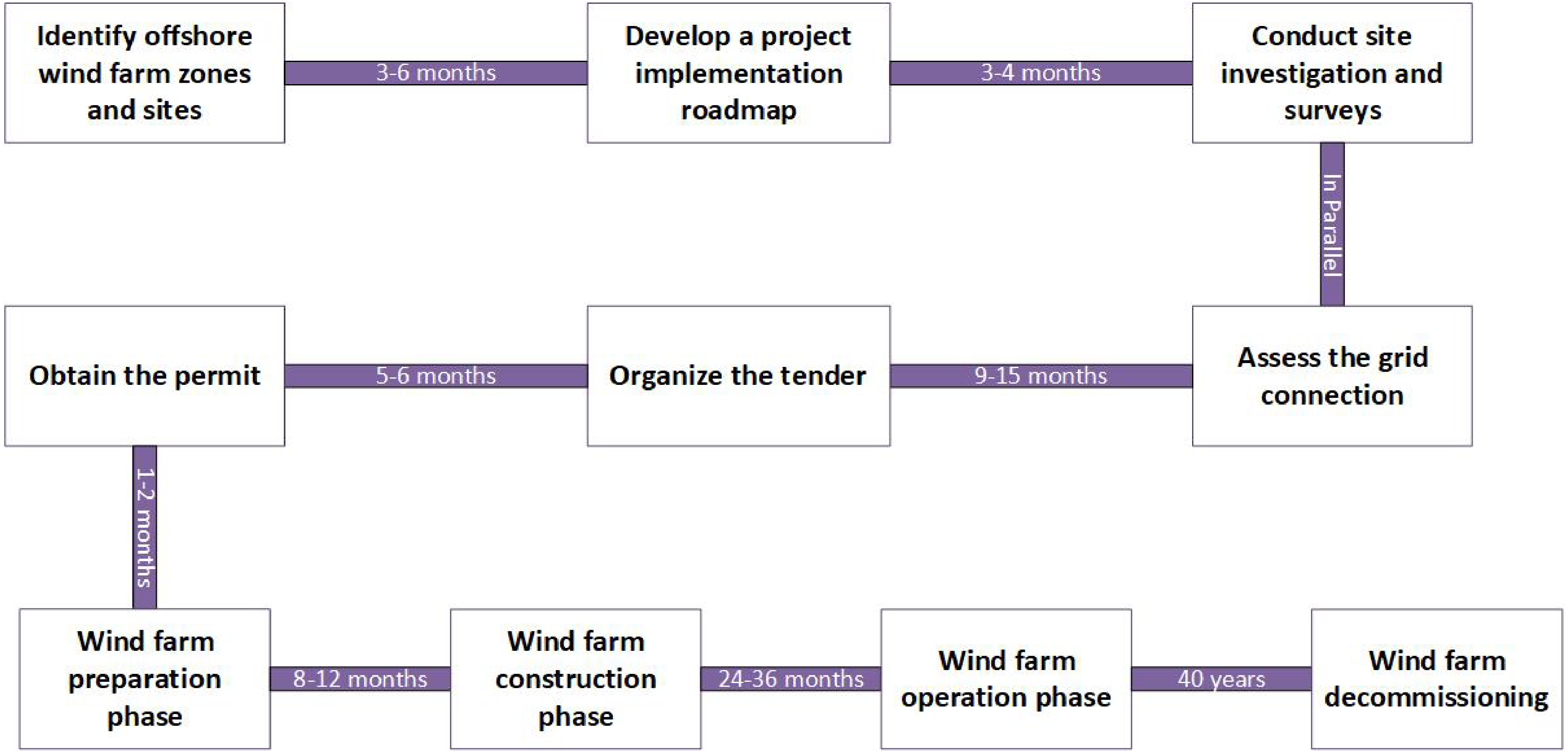

Figure. Illustrative offshore wind development timeline for Bangladesh

Source: Adapted from Asian Development Bank, Joshi (2024)

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Offshore Wind Market Development

Components of a Viable Offshore Industry

Market visibility and national targets.

Regulatory certainty and site control: political cooperation for equitable sharing of ocean space.

Port facilities to serve local installations and service ports.

Adequate vessels: heavy lift, survey, installation, crew transfer, and cable lay vessels.

Bulk transmission access: political support for coordinated actions.

Industry supply chain access and workforce: leverage existing capabilities, train, and develop.

Continued **cost reduction** to competitive pricing.

Enabling Policies and Regulations

Spatial Planning:
Effective geospatial and marine planning to identify suitable locations.

Regulatory Framework:
Ensure that offshore wind farms can receive the permits needed for construction and operation.

Environmental Considerations:
Policies should incorporate robust environmental assessments and mitigation measures.

Grid Connection:
Includes technical requirements for grid integration, coordination with grid operators, and grid connection agreements.

Financing and Incentives:
Policies outlining financial incentives to encourage private sector investment.

Local Content and Workforce:
Encourage the development of local content, workforce, and technology transfer.

Health and Safety:
Set standards for the health and safety of the workers throughout (construction, operation, and maintenance).

Stakeholder Engagement:
Policies should emphasize stakeholder engagement and community consultation throughout development.

Decommissioning:
Policies that address the end-of-life of an offshore wind farm (decommissioning, refurbishment, recycling, etc.).

Port Infrastructure

Investments in Ports

- **Manufacturing / fabrication sites**: where major offshore wind components are built, stored, and transported.
- **Marshaling / integration sites:** where components are delivered, stored, and loaded onto specialized vessels for assembly at site or assembled on floating platforms that can be towed to the project site.
- **Operation and maintenance sites**: act as a base for vessels that travel to the offshore wind project to perform regular maintenance activities.

Figure. Component staging at port

Figure. Installation vessel

Port Needs

- Space to stage large components
- High bearing capacity at quayside
- Heavy lift cranes
- Adequate channel depth for large vessels
- Ample air draft.

Source: Shields et al. (2023a)
Images: Siemens AG, Lyfted Media for Dominion Energy

Offshore Wind Marshalling Ports

Parameter	Ideal Fixed-Bottom Value
Water Draft (m)	6-7 (*feeder barge*) 12 (*wind turbine installation vessel*)
Air Draft (m)	> 150
Laydown Area (hectares)	20
Berth Length (m)	200-400
Number of Berths	2
Bearing Capacity (t/m^2)	15

Source: Shields et al. (2022)

Figure. Foundations at an offshore wind marshalling port

Offshore Wind Operations & Maintenance

Parameter	**Approximate Criteria for O&M Ports**
Water Draft (m)	6-9
Air Draft (m)	> 150
Area (hectares)	2-4
Berth Length (m)	90
Bearing Capacity (t/m^2)	0.5-2

Source: Shields et al. (2023a)

Figure. Offshore wind turbine service vessel

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Transmission Planning

- Grid integration
  - Point of interconnection
  - Delivery to load centers
  - Contribution to system reliability
  - Phased expansion with offshore wind deployment
- Subsea cable route planning
  - Seabed: sensitive habitat, canyons
  - Existing infrastructure: cables, pipelines
  - Traffic lanes and fishing activities
- Cable landfall

Figure. High voltage AC transmission lines near the office of the Power Grid Corporation of Bangladesh

Image: Prateek Joshi (NREL)

Supply Chain Considerations

Transmission Cables: Offshore wind projects have a high demand for cables for transmitting electricity generated by the wind turbines.

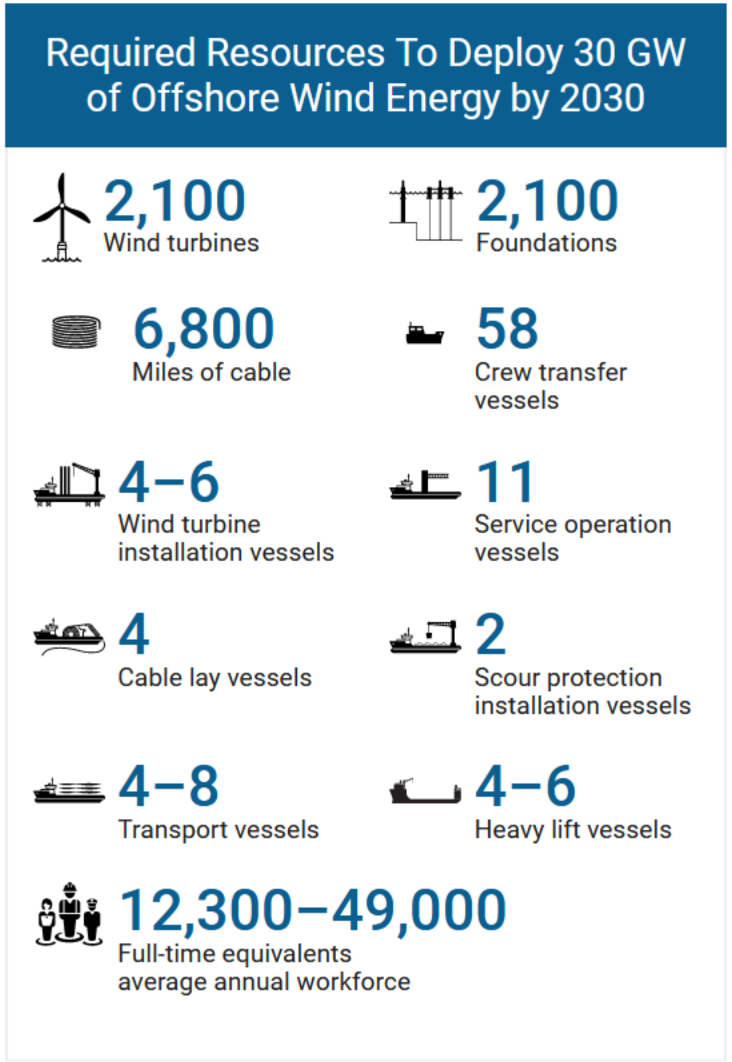
Steel Components: Offshore wind turbines rely on steel for key structural components, including the tower, and in foundations such as monopiles, jackets, or floating platforms.

Concrete and Rock: Local companies are well positioned to supply concrete and rock, which are used for scour protection of underwater components and in some offshore wind turbine foundation designs.

Marshalling of Foreign Materials and Equipment: Local public/private organizations and companies can play a crucial role in marshalling foreign-produced materials and equipment required for offshore wind farms.

Provision of local workforce at different levels: engineers, technicians, workers, other staff who are experts in specific disciplines, like safety, telecommunication, logistics, regulatory compliance, as well as suppliers of "board and lodging" and any other services needed.

Figure. U.S. example of offshore wind supply chain needs assessment



Source: Shields et al. (2023b)

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Workforce Development

Offshore wind industry segments:

Development: Jobs associated with site assessment, plant design, permitting, financing, project management, and other preconstruction activities.

Manufacturing and supply chain: Jobs for various components produced at multiple tiers of the manufacturing process, from engineering and design of components to production.

Ports and staging: Jobs involved in ports and staging, such as terminal crews and logistics and management roles located portside.

Maritime construction: Jobs operating at sea to install projects, including the marine crew, engineers, and installation crews.

Operations and maintenance (O&M): Jobs that involve operating and maintaining a project during its lifetime, including wind technicians and plant managers.

- Most offshore wind energy industry roles require **specialized training and relevant experience** in a skilled trade, whereas only some roles require advanced degrees (e.g., bachelor's degree or higher).
- Policymakers, labor organizations, and educational institutions can create **new education training programs** and **standardized** role definitions, requirements, or credentials.
- Transferable skillsets from the offshore oil and gas industry.

Source: Stefek et al. (2022)

Considerations for Offshore Wind in Bangladesh

Fixed vs. Floating Turbines for Bangladesh

Other factors influencing substructure technology choices:

- Seabed geotechnical conditions (such as boulders, soft soils, slopes, etc.)
- Port conditions (navigation channel widths and depths, height restrictions from bridges, etc.)
- Manufacturing or logistical challenges (areas for component staging/manufacturing, weight bearing capacities, materials and labor availability, etc.).

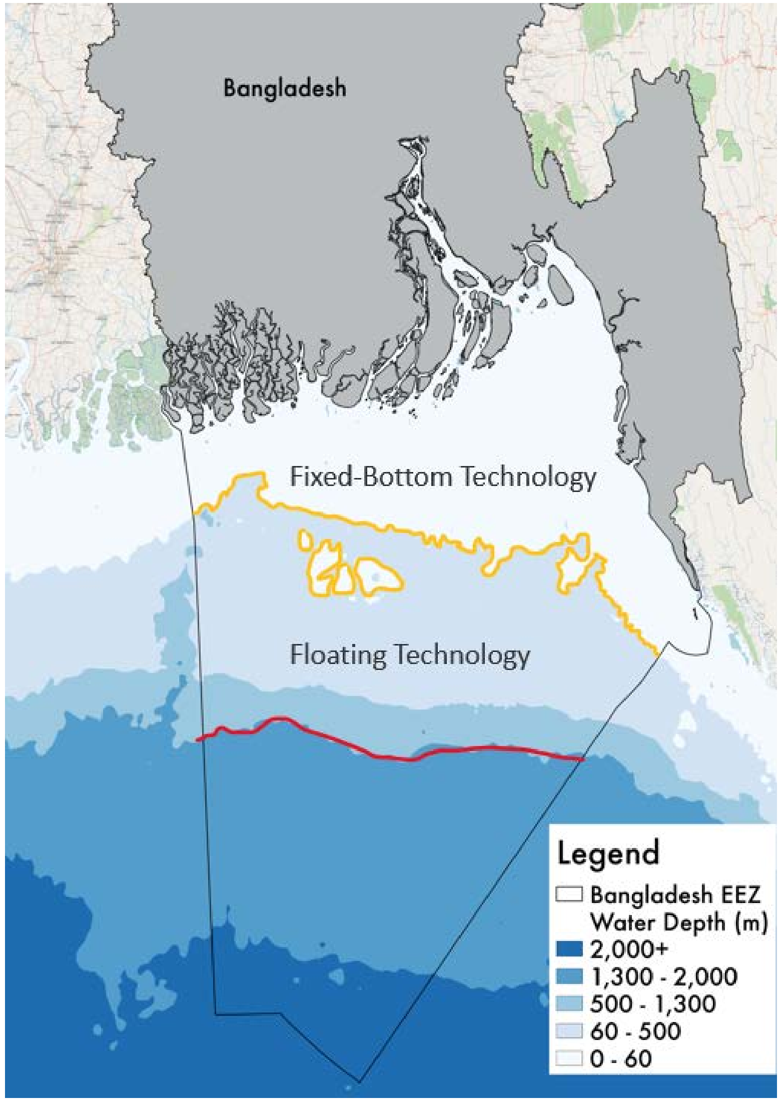

Figure. Offshore waterbody depth for Bangladesh, including areas for fixed and floating offshore wind technologies

Image: Gabriel Zuckerman (NREL)

Offshore Wind Resource in Bangladesh

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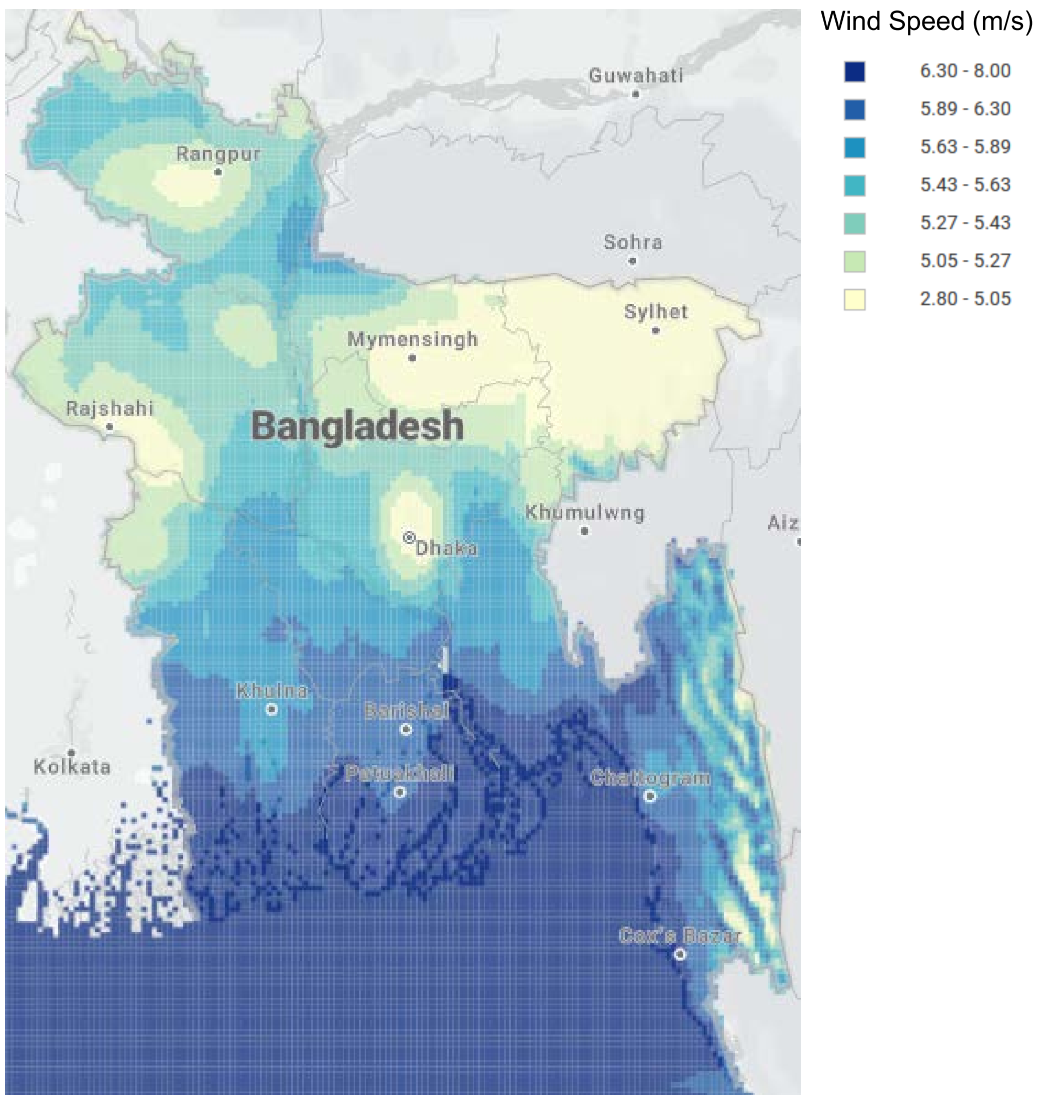
- Offshore wind speeds are higher in Bangladesh compared to onshore wind speeds.
- Average offshore wind speeds (at 160 meter hub height) range from 6.3 to 8 meters/second.



https://www.re-explorer.org/

Figure. Onshore and offshore wind speeds in Bangladesh at a hub height of 160 meters

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Bangladesh Offshore Wind Supply Curves

Utility-Scale Wind: Offshore

Scenario	Buffer from Shore	Marine Protected Areas
All	*10 km*	*Exclude*

rev

https://www.nrel.gov/gis/renewable-energy-potential.html

- Technical assumptions:
    - 15 MW turbine, 150 m hub height, 240 m rotor diameter, 5.35 MW/km^2 capacity density, assumed wake loss of 7.1%.
- Financial assumptions:
    - Capital cost scaled by plant size after exclusions are considered (depends primarily on distance from construction and operations port and water depth).
    - Starting site-based capital cost assumption: 225,506,553 BDT/MW.
    - Starting site-based O&M cost assumption: 7,288,522 BDT/MW-year.
    - Associated cost reductions with future global deployment trajectories based on NREL's FORCE model and expert elicitation surveys (Wiser et al. 2021).
    - Fixed charge rate: 5.1%.
- Assumed construction in 2030.

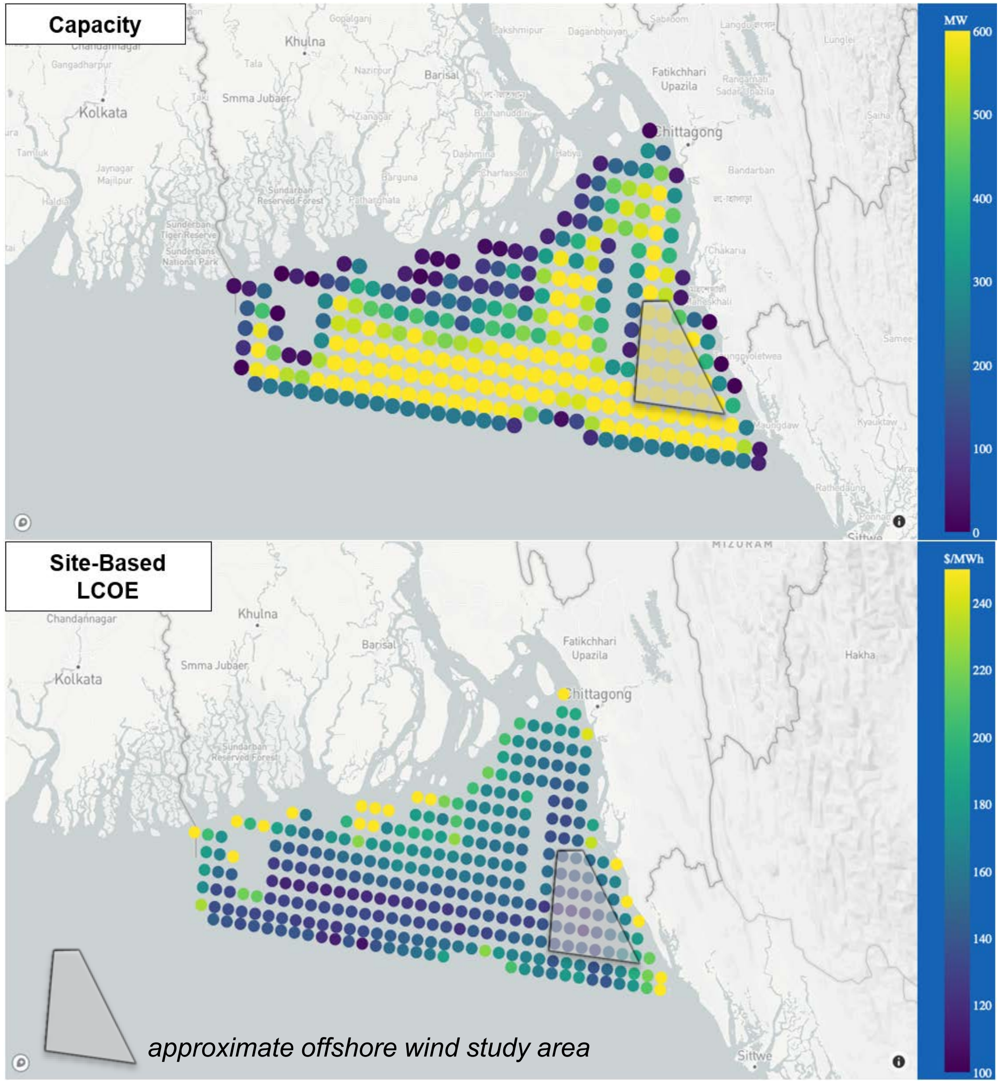

Figure. Offshore wind technical potential capacities and site-based levelized cost of electricity (LCOE) based on high-level assessment using preliminary assumptions

Image: Gabriel Zuckerman (NREL)

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Port Development in Bangladesh

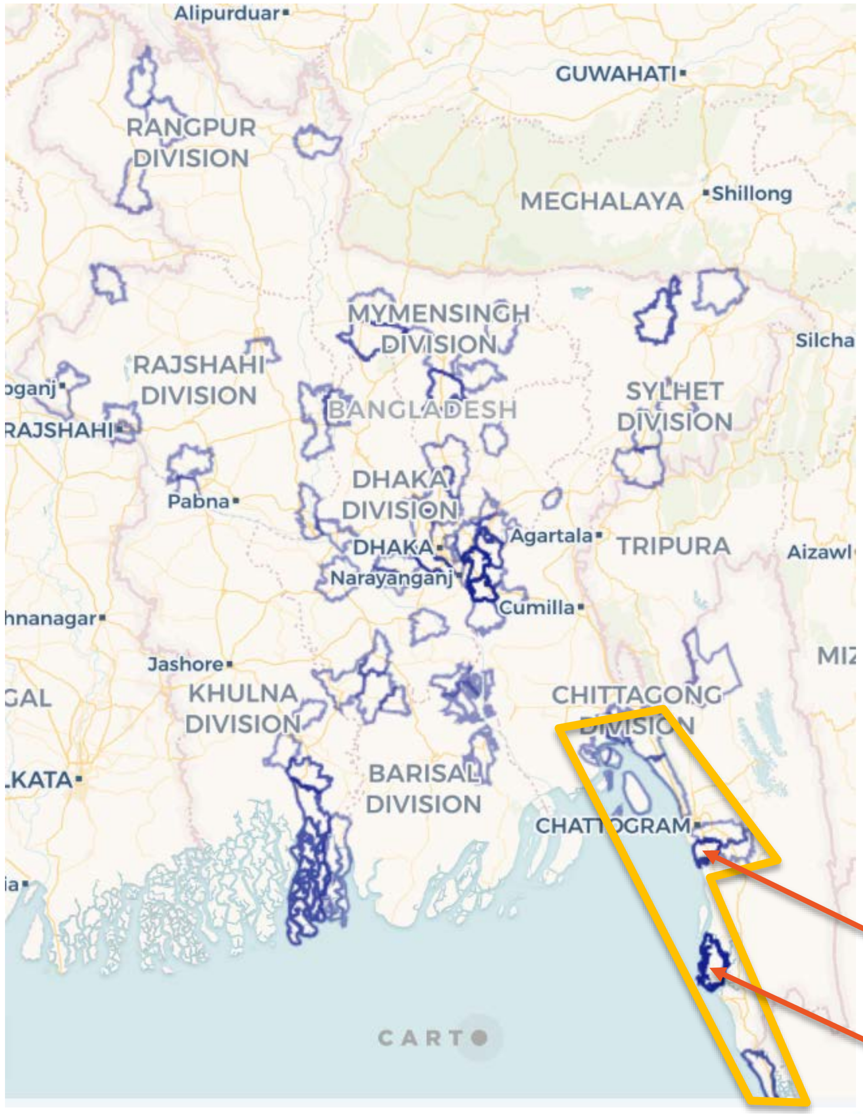

Figure. Upazilas with economic zones

Source: Joshi et al. (2023)

Government and Private-Owned Economic Zones

- Economic zones managed by the Bangladesh Economic Zones Authority (BEZA).
  - Under development to boost domestic manufacturing, attract private and foreign investment, generate thousands of jobs, and grow the export market.
- Coastal economic zones and major ports, such as the Chittagong Port and the Matarbari Deep Sea Port (first in the country, currently under construction).
  - Prime candidates to be centers of Bangladesh's future offshore wind industry (i.e., manufacturing, construction, and staging ports).
  - First offshore wind development site in Bangladesh located off coast of Matarbari port.

Chittagong port and economic zones

Matarbari port and economic zones

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Grid Infrastructure in Bangladesh

Consider the onshore electrical infrastructure, transmission, and substation capacity in areas like Cox's Bazar and Chittagong, to account for potential upgrades to accommodate offshore wind generation

(in addition to economic zones, onshore renewable energy zones, port development, and other technologies such as energy storage and hydrogen).

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Figure. Bangladesh transmission system map (June 2020)

Areas (transmission lines, substations, etc.) of the Bangladesh grid likely to be most impacted by offshore wind development.

Image: Power Grid Company of Bangladesh (PGCB)

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Case Study: Philippines

World Bank Offshore Wind Roadmap (2022)

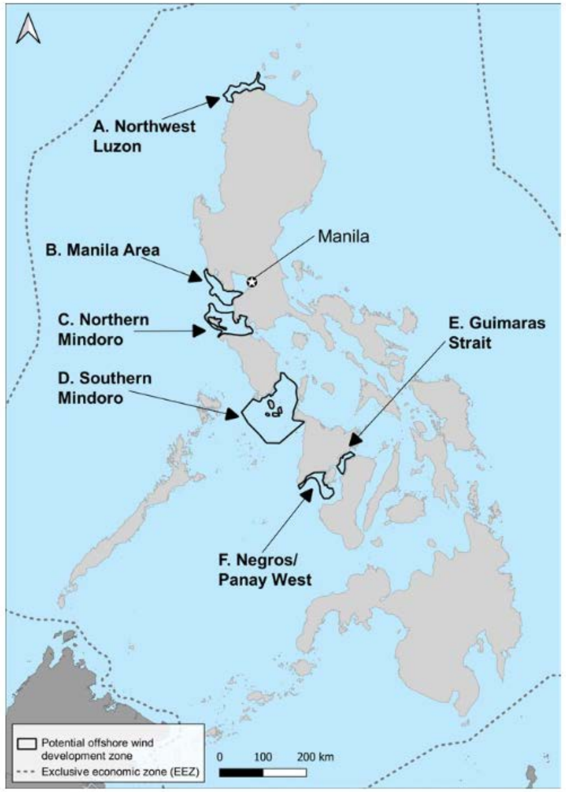

Figure. Potential offshore wind development zones

Preliminary marine spatial mapping and resource assessment to identify candidate development zones.

RMI Pre-Feasibility Analysis (2024)

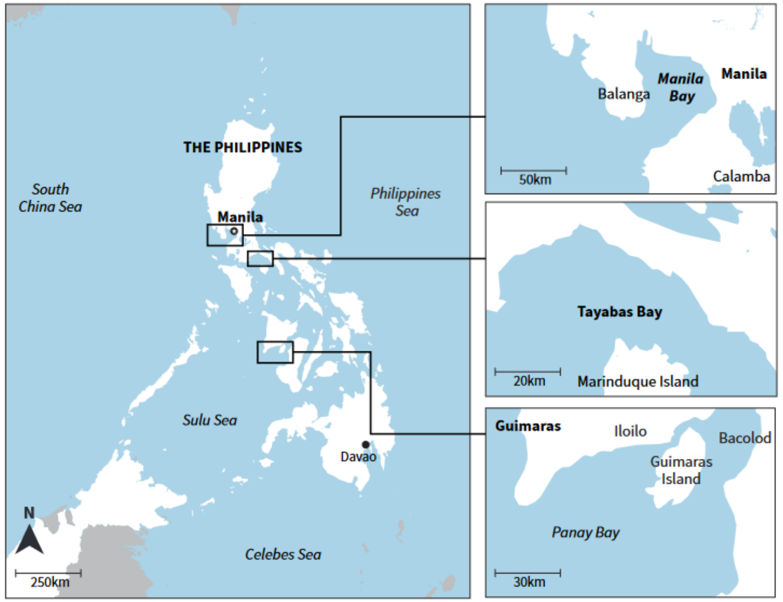

Figure. Three priority offshore wind zones selected for pre-feasibility assessment

Pre-feasibility assessment of three offshore wind zones, assessing port infrastructure, grid requirements, etc.

NREL Analysis (ongoing)

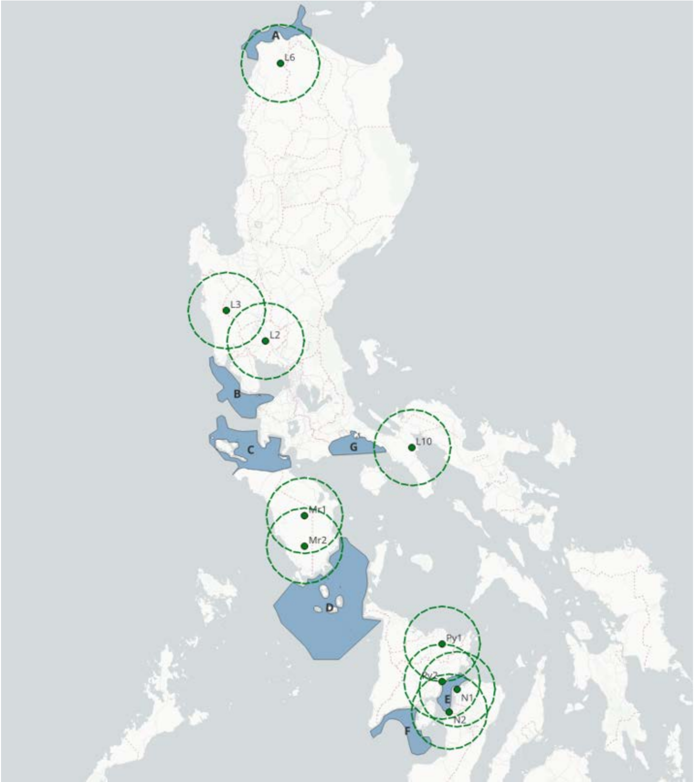

Figure. Potential offshore wind development zones and onshore renewable energy zones

Developing hourly capacity factor data and supply curve data for offshore wind zones and linking offshore wind zones with onshore renewable energy zones.

Sources: World Bank (2022), Buescher et al. (2024)

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Case Study: Vietnam

- Offshore wind targets: 6 GW by 2030, 91 GW by 2050.
- Most renewable energy projects are concentrated in the central and southern regions of Vietnam.
  - Capacity of the grid is not sufficient to transmit energy from the south to north when required.

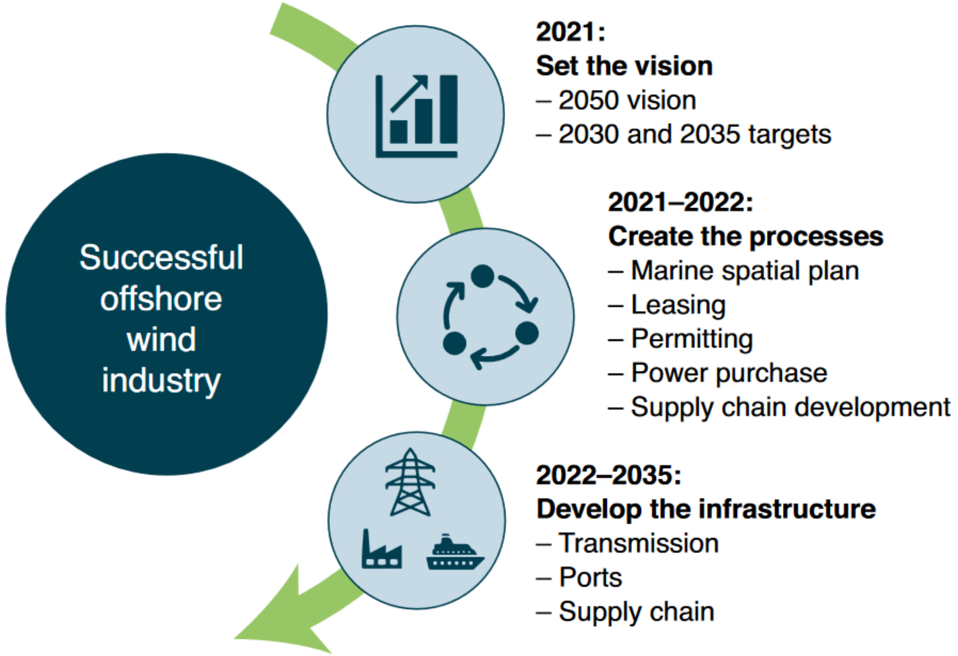

Figure. Vietnam offshore wind roadmap developed by World Bank and BVG Associates

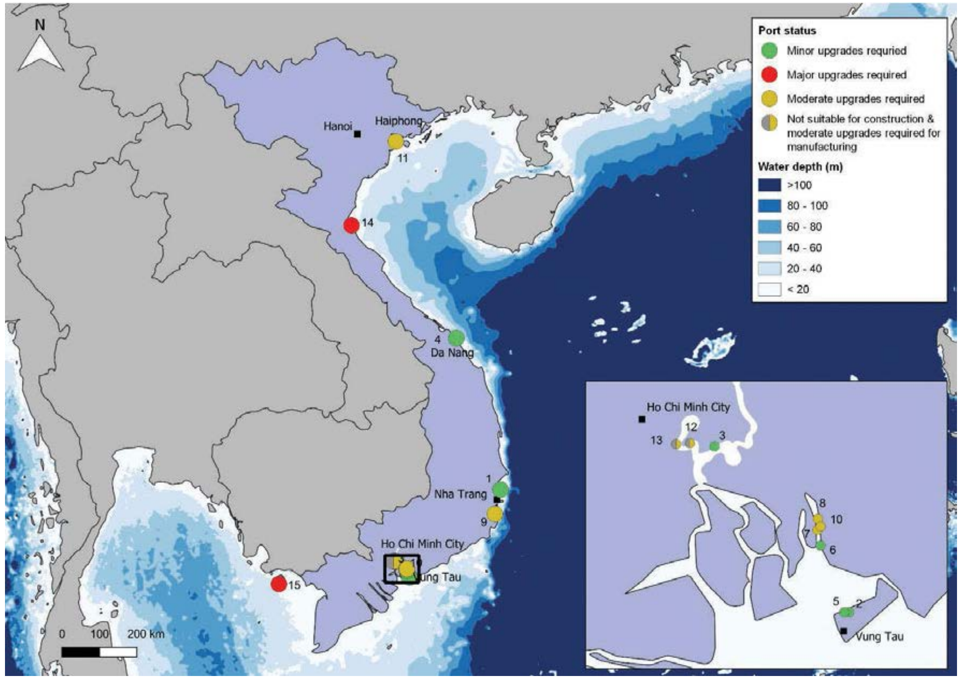

Figure. Potential offshore wind manufacturing and construction ports in Vietnam

Source: Lee and Zhao (2024), World Bank (2021)

Thank You!

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